Supplement A1

Human Research Program
Integrated Research Plan

July 2009

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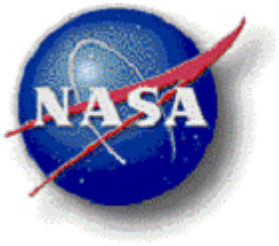

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1.0 INTRODUCTION AND BACKGROUND

Crew health and performance is critical to successful human exploration beyond low Earth orbit. The Human Research Program (HRP) is essential to enabling extended periods of space exploration because it provides knowledge and tools to mitigate risks to human health and performance. Risks include physiological and behavioral effects from radiation and hypogravity environments, as well as unique challenges in medical support, human factors, and behavioral or psychological factors. The Human Research Program (HRP) delivers human health and performance countermeasures, knowledge, technologies and tools to enable safe, reliable, and productive human space exploration. Without HRP results, NASA will face unknown and unacceptable risks for mission success and post-mission crew health.

This Integrated Research Plan (IRP) describes HRP's approach and research activities that are intended to address the needs of human space exploration and serve HRP customers and how they are integrated to provide a risk mitigation tool. The scope of the IRP is limited to the activities that can be conducted with the resources available to the HRP; it does not contain activities that would be performed if additional resources were available. The timescale of human space exploration is envisioned to take many decades. The IRP illustrates the program's research plan through the timescale of early lunar missions of extended duration.

The IRP serves several purposes for the Human Research Program. The IRP…

- provides a means to assure that the most significant risks to human space explorers are being adequately mitigated and/or addressed;
- shows the relationship of research activities to expected outcomes and need dates;
- shows the interrelationships among research activities that may interact to produce products that affect multiple HRP Element, Project or research disciplines;
- accommodates the uncertain outcomes of research and technology activities by including decision points that lead to potential follow-on activities;
- shows the assignments of responsibility within the program organization and, as practical, the proposed acquisition strategy;
- shows the intended use of research platforms such as the International Space Station (ISS), NASA Space Radiation Laboratory (NSRL), and various space flight analog environments; and
- shows the budgeted research activities of the Human Research Program, but does not show all budgeted activities, as some of these are enabling functions, such as management, facilities, and infrastructure.

1.1 CONTEXT OF THE INTEGRATED RESEARCH PLAN

There are three foundational documents to the HRP:

1. Program Requirements Document (PRD)
2. Evidence Book
3. Integrated Research Plan (IRP)

The PRD describes the high-level requirements that the program must meet. The Evidence Book provides the scientific basis for the risks that are contained in the PRD, and the IRP describes the approach to addressing the requirements in the PRD. The relationship of these HRP documents is illustrated in Figure 1.1.

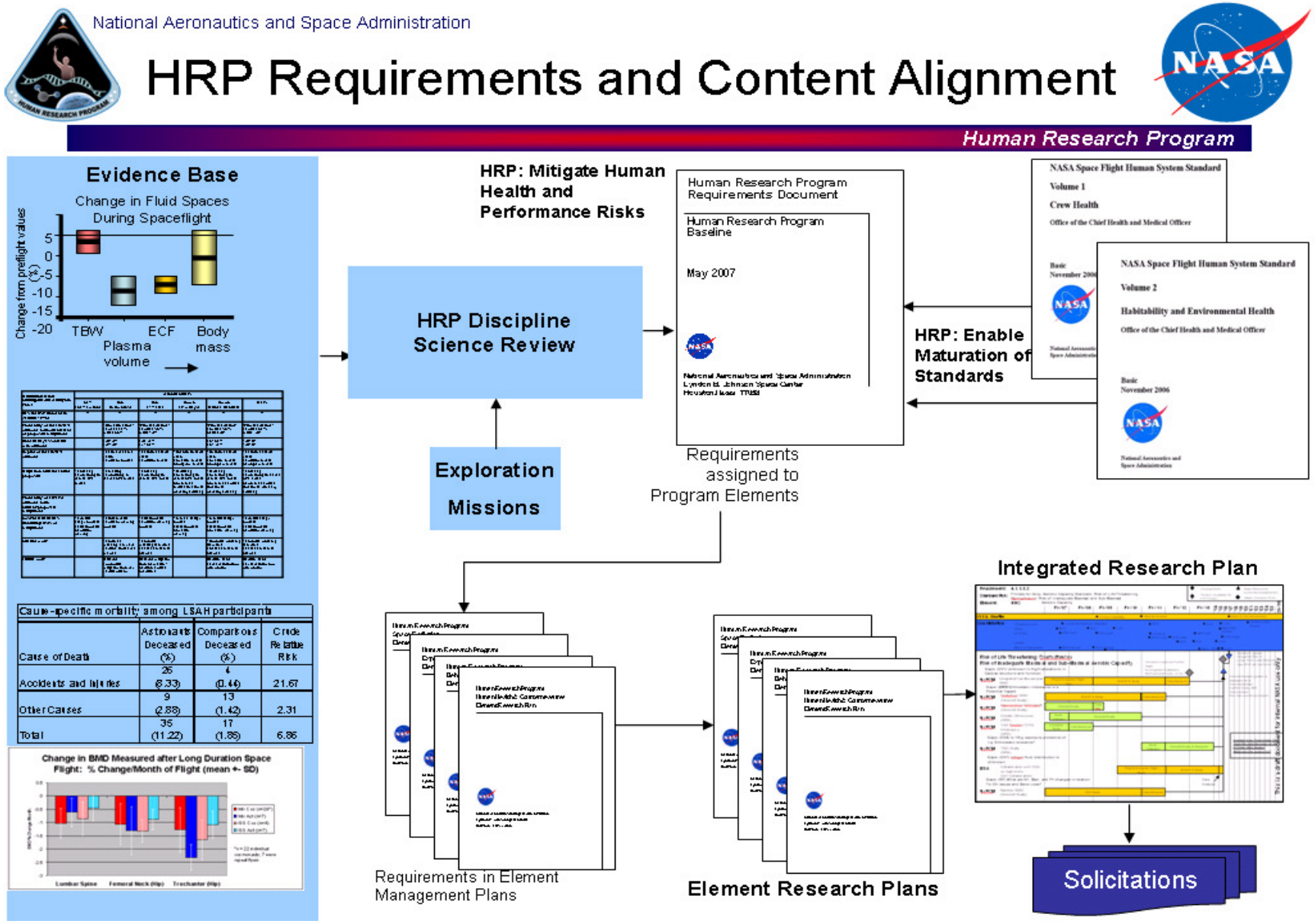


Figure 1.1: HRP Requirements and Content Alignment

1.2 PROGRAM REQUIREMENTS DOCUMENT

The HRP's top-level requirements are maintained in the Exploration Systems Mission Directorate (ESMD) Exploration Architecture Requirements Document (EARD), ESMD-EARD-08-07, Rev.-. The purpose of the EARD is to translate the expectations of stakeholders, both inside and outside NASA, for the next generation U.S. Space Exploration mission, into requirements that will flow down to the implementing organizations. The EARD allocates the following top requirements to the HRP.

- *[Ex-0061] NASA's Human Research Program (HRP) shall develop knowledge, capabilities, countermeasures, and technologies to mitigate the highest risks to crew health and performance and enable human space exploration*
- *[Ex-0062] NASA's HRP shall provide data and analysis to support the definition and improvement of human spaceflight medical, environmental and human factors standards*
- *[Ex-0063] HRP shall develop technologies to reduce medical and environmental risks and to reduce human systems resource requirements (mass, volume, power, data, etc.)*

The PRD decomposes those requirements into lower level requirements that are then allocated to the HRP Elements. The requirements in the PRD are divided into three categories: requirements related to human system standards, requirements related to human health and performance risks, and requirements related to provision of enabling capabilities. The HRP comprises the following major Program Elements: Behavioral Health and Performance (BHP), Exploration Medical Capability (ExMC), Human Health Countermeasures (HHC), ISS Medical Project (ISSMP), Space Human Factors and Habitability (SHFH), and Space Radiation (SR). Each element incorporates their respective PRD requirements into their specific element management plans. The research elements subsequently derive a research plan to address the requirements.

1.2.1 STANDARDS

The PRD requires that the HRP make recommendations for updates to the Space Flight Human System Standards (SFHSS). The SFHSS, Volume 1 (NASA-STD-3001, Vol. 1), describes Levels of Care required for human spaceflight missions, Permissible Exposure Limits, Permissible Outcomes, and Fitness for Duty Standards for crewmembers on exploration missions, among other things, and was first baselined on March 5, 2007, by the Office of the Chief Health and Medical Officer (OCHMO). Essentially, these are the definition of acceptable levels of risk for human health and performance associated with spaceflight. By comparing these standards with the existing evidence and knowledge base, the HRP can identify and quantify the risks associated with human exploration missions, and derive the research necessary to lower the risk.

SFHSS, Volume 2 (Spaceflight Habitability and Human Standards) provides the comprehensive set of requirements associated with Human Factors and Habitability. These standards must be met by the Constellation program in development of each vehicle and supporting equipment utilized in space exploration. Through comparison of these standards with the state of the art in engineering design, the HRP can identify areas where research is necessary to help the Constellation program meet these requirements.

The HRP has two main responsibilities concerning the standards. In some cases, the SFHSS has a wide band of uncertainty. The HRP must conduct research to help refine and narrow the uncertainty associated with the standard. In other cases, emerging evidence or knowledge may indicate that the standards are not written in a way that captures a complete set of relevant considerations. The HRP is required to address the modification of such standards. Additional research may be required to facilitate this. The PRD decomposes the top-level requirement into the specific standards and allocates the requirement to inform these standards to the appropriate HRP Element.

1.2.2 RISKS

The HRP identifies risks relevant to the Chief Health and Medical Officer and to the health and human performance aspects of the Constellation Program. The HRP utilizes the Chief Medical Officer's Human System Risk Board (HSRB) to identify risks requiring research. The PRD allocates requirements to quantify, mitigate, or monitor these human system risks to the appropriate Element within the HRP. The PRD, however, does not establish priority for the risks.

The risks in the PRD are arranged in two groups based on the level of available evidence. Risks for which substantial evidence exists are listed in Table 1 while those that cannot be supported or refuted by available information at this time are in Table 2. This IRP addresses each of the risks in the priority order described in Section 2.0 in the PRD.

1.3 EVIDENCE BOOK

The HRP Evidence Book documents WHY the risks are contained in the PRD. It is a record of the state of knowledge for each risk in the PRD and, therefore, provides bases for analyses of the likelihoods and consequences for each of the risks. As such, the Evidence Book, a compilation of all the evidence-based risk reports, makes important data accessible and available for periodic review. The Evidence Book is publicly available at the following internet address - http://humanresearch.jsc.nasa.gov/elements/smo/hrp_evidence_book.asp.

The documentation of evidence for each risk in the PRD is in the form of a review article that is aimed at a scientifically-educated, non-specialist reader. The documentation is broken into the following parts:

The body of each risk review contains a narrative discussion of the risk and its supporting evidence.

1. Declarative statements concerning the risk are supported by a description of the evidence, whether published or unpublished.
2. Relevant published references are listed at the end of the report.
3. Data that are significant or pivotal are summarized in text, tables, and charts in sufficient detail to allow the reader to critique and draw conclusions, especially when a published reference is not available.
4. In a similar fashion, the authors indicate, as appropriate, whether the data are from human, animal, or tissue/cell/molecular studies.
5. Evidence from space flight (including biomedical research, Medical Requirements Integration Document [MRID] data, and operational performance or clinical

observations) is presented first, followed by ground-based evidence (including space analog research and non-space analog biomedical or clinical research).

6. When evidence is from ground-based studies, authors discuss why these results are likely to be applicable in the space environment, offering available validation information for the use of these ground-based systems.

The National Academies of Sciences Institute of Medicine reviewed the risk reports to validate that they provide sufficient evidence that the risk is relevant to long-term space missions. Their conclusions and recommendations are given in the IOM publication, *Review of NASA's Human Research Program Evidence Books. A Letter Report,* Washington DC: The National Academies Press, 2008.

Some Risk Reports will be published through refereed journals specific to the appropriate disciplines. In some cases, when the evidence reports are not published in a journal, the HRP will publish them in NASA Technical Reports. Further, all evidence reports will be made available on the HRP external website.

As new evidence is gathered, the Risk Reports will be updated. If new evidence indicates that a risk should be retired or that a new risk should be added, the HRP will, after thorough review with the HSRB, take the appropriate action to modify the PRD and update the Evidence Book accordingly.

1.4 THE INTEGRATED RESEARCH PLAN

The IRP documents the CRITICALITY of each risk:

- WHAT tasks are necessary to fill gaps,
- WHEN those tasks will be accomplished and their deliverables provided to the stakeholder,
- WHERE they will be accomplished (e.g., use the International Space Station, use a ground analog, etc.), WHO will accomplish them (which project or organization within the HRP), and
- What is being PRODUCED.

1.4.1 Criticality to Missions

Three categories of criticality have been developed for the mitigation of each of the risks: 1) Critical, 2) Important, and 3) Desirable.

Each of the three categories is applied to two different mission scenarios, the lunar mission(s) (including the lunar outpost missions) and the Mars mission.

The criticality of a risk for either a lunar or a Mars mission alone is not sufficient to determine the optimum level of activity (or budget) or timing for research investments. Other factors combine to determine the research approach, such as limited availability (of certain necessary resources like the Space Shuttle and the ISS), exceptionally long lead times (needed to improve understanding and mitigation of radiation risks), or the amount of risk reduction that can be obtained with a specific set of resources. All of the factors needed to determine the research approach are not explicitly represented in the IRP, only the resultant research plan.

For reference, each risk heading in this document is labeled with an abbreviated version of the Lunar and Mars criticalities.

Criteria for criticality of the risks applicable to the lunar outpost and Mars mission(s) are:

- ***Critical*** *to Quantify and Reduce Prior to the Lunar Outpost or Mars Missions*.
  Absence of additional data or risk mitigation countermeasures (beyond what is available at the approval date of this document) would likely delay Lunar Outpost or Mars Missions, even if all other elements of the mission were ready (e.g., if the launch systems, Extravehicular Activity (EVA) systems, landing and life support systems were ready). The lack of this data or an adequate additional mitigation would leave NASA with unacceptable uncertainty in the residual risk, and/or with unacceptable absolute risk to human health and performance, thus precluding NASA's ability to embark on the mission. Critical risks for lunar outpost are identified by the abbreviation **LUNAR OUTPOST-C** and for Mars by the abbreviation **MARS-C**.
- ***Important*** *to Quantify and Reduce Prior to the Lunar Outpost or Mars Missions*.
  Absence of additional data or risk mitigation countermeasures in this area (beyond what is available at the approval date of this document) would likely not delay lunar outpost or Mars missions, if all other elements of the mission were ready (e.g., if the launch systems, EVA systems, landing and life support systems were ready). This would leave the mission with significant residual or unknown risk however. Mission loss or major impact to post-mission crew health could occur if this risk is not quantified and reduced. Important risks for lunar outpost are abbreviated **LUNAR OUTPOST-I**, and for Mars as **MARS-I**.

- ***Desirable*** *to Quantify and Reduce Prior to the Lunar Outpost or Mars Missions*.
  The absence of data or risk mitigation countermeasures in this area (beyond what is available at the approval date of this document) would not delay the lunar outpost or Mars missions if all other elements of the mission were ready (e.g., if the launch systems, EVA systems, landing and life support systems were ready). However, quantifying and reducing the risk would reduce the risk for that particular discipline. Engineering or operational workarounds/constraints could be avoided if this risk were quantified and/or reduced. Desirable risks for lunar outpost are abbreviated **LUNAR OUTPOST-D**, and Mars as **MARS-D**.

Ultimately, assessment of the criticality is based on the likelihood and consequence of the risks, the gaps, and the tasks, coupled with the uncertainty in risk projections. Assessment involves integration and comparison of risk factors and the impact each task may have on the reduction of the overall risk to the mission or the crew, given different mission scenarios, research approaches, and outcomes.

The HRP will use the Risk Management Analysis Tool (RMAT) to categorize and document the assessment of the risks and to document priority. At present, the RMAT is a two-dimensional tool. There is no integrated or validated assessment tool that will allow the use of the RMAT for cross-comparison or prioritization of risks or gaps now. Until the availability of such a tool, the HRP will rely on expert opinion, with consideration of the RMAT and existing evidence. The HRP's Science Management Office has the responsibility of prioritizing the HRP's research portfolio as described in the HRP Science Management Plan (HRP-47053 Rev. C), Paragraph 3.1.

1.4.2 TASKS REQUIRED TO FILL THE GAPS (WHAT)

For each risk, the appropriate HRP Elements identified gaps in the risk's state of knowledge and NASA's ability to mitigate the risk. Further, the HRP Elements identified specific research tasks required to fill each gap and the product(s) resulting from the tasks. This Integrated Research Plan lays out the risk, gaps, tasks, and resulting products in a notional schedule tied to the appropriate Exploration milestones for which the products will be needed. The rationale for the selected approach is documented in the text portions of the IRP.

This plan includes activities that are more than "Research or Technology Development." In some cases, the activities reported in this document are not explicitly "research" or "technology development," but are included to ensure logical completeness in describing those activities necessary to mitigate the risks. Examples are data mining activities, the results of which are pivotal in defining further steps in the research path, and hardware evaluations that would further the engineering approach to risk mitigation.

Key Decision Points are built into the IRP, wherein the HRP will evaluate data with respect to closing the research gap, as well as the impact on the overall likelihood or consequence of the risk. The results of this analysis help formulate the next steps. In some cases, likelihood with existing countermeasures will not be high enough to warrant proceeding with more research. This risks-gaps-tasks-deliverables detail is required to ensure completeness in addressing the risks.

1.4.3 Schedule Drivers (WHEN)

The Integrated Research Plan describes a plan of knowledge production and technology development to address risks associated with human space flight. As new knowledge is gained, the required approach to research and development may change. The IRP attempts to describe a plan of research looking forward many years into the future. The fidelity of the IRP is quite high in the near term (2009-2010), but decreases with time. The IRP will be revised and updated annually based on available resources, Constellation mission development, other schedule constraints, achievement of key milestones, and consideration of new evidence gained from the previous year.

1.4.4 RESEARCH PLATFORMS (WHERE)

The HRP uses various research platforms and data sources to address gaps in knowledge. Historical data derived from ground and spaceflight studies form the basis of the HRP Evidence Reports, with the intention of ensuring that the HRP does not duplicate effort already expended. Many of these activities appear in this IRP as "data mining," although not explicitly "research."

Data mining involves gathering and analyzing data from historical space flights via the Longitudinal Study of Astronaut Health and other sources, spaceflight operational data such as landing performance and simulator performance data to identify possible correlation with physiologic or psychological function, and relevant data from ground studies (NASA sponsored and otherwise).

The HRP utilizes the Space Shuttle and the International Space Station to conduct research requiring the unique environment of space. The spaceflight data primarily identify and/or quantify physiological and behavioral changes to the human system occurring in the

microgravity environment. The ISS is utilized to both validate potential countermeasures and as an analog for long-duration Mars missions.

NASA has laid out specific schedule milestones/constraints for implementation of the Vision for Space Exploration (VSE). The Shuttle retirement in 2010, the Orion vehicle use in 2014, and the first lunar sortie by 2020 together create urgency for the acquisition of knowledge. The use of the Shuttle and ISS platforms, in several cases, is critical to obtaining the required knowledge to build products supporting longer, more challenging missions. The Shuttle retirement in 2010 and the uncertainty in the completion of ISS operations levies significant constraints on available flight resources, thus some research is accelerated to take advantage of these vehicles while available. Where possible, the HRP will utilize analog environments to perform the research required to fill gaps in knowledge, preserving the limited flight resources for only those that cannot be addressed elsewhere. These data are used as an analog to a long-duration Mars mission because the ISS is the only resource of its kind. The HRP will accelerate some of the research from this resource to facilitate future long-term stays in microgravity on exploration missions that could otherwise be delayed pending such a mission design.

There are several analog environments utilized by the HRP, some owned and operated by HRP, some by NASA, and others operated by other agencies. Each analog environment is assessed for its characteristics that mimic portions of the flight environment, the fidelity of the analog. No ground-based analog can serve to simulate the flight environment completely, thus each analog use is selected based on its important flight-like characteristics specific to the task objectives. Several analogs often will be required to fill a gap, and, in all cases, analog findings are validated in the space flight environment.

The Flight Analogs Project coordinates utilization of ground based research analogs to complement space research. Throughout the IRP, tasks requiring the use of specific analogs are identified. The bed rest analog mimics some of the physiological changes induced by weightlessness, using a bed rest model with a 6^{o} head-down tilt. The NASA Extreme Environment Mission Operations (NEEMO) analog and Antarctic missions provide mission-like settings and interactions that incorporate the constraints of working in extreme environments. The Haughton-Mars and Devon Island analogs to provide rugged terrain and mission-like interactions to address specific lunar surface system concepts related to EVA and other factors related to behavioral health and performance. In some cases, the HRP also utilizes operational mission environments, such as the Phoenix Mars Scout Lander, to obtain data relevant to the behavioral health and performance of the ground crews supporting long duration spaceflight missions. Such data provide valuable lessons for future exploration missions. Isolation chambers also provide mission-like ground-to-crew and crew-to-crew interactions that facilitate behavioral studies of team cohesion, workload, fatigue, and sleep. The NASA Space Radiation Laboratory (NSRL) is a unique ground-based analog. This facility is owned and operated by the Department of Energy's (DoE) Brookhaven National Laboratory, under a contract with the HRP. HRP utilization of the NSRL is managed by the Space Radiation Program Element.

As NASA prepares to send crewmembers back to explore the Moon for periods of up to six months, questions arise regarding the impacts of the lunar environment on the health, safety, and performance of the explorers. Among the environmental characteristics of concern is the relatively small force of gravity on the Moon, which is approximately one-sixth of that on Earth. "Space normal" is defined for this document as the normal human response to prolonged space flight. While the normal human response to prolonged microgravity exposure has been fairly

well characterized during (and after) orbital space flight missions, little is known about the human physiological responses to prolonged fractional gravity exposure. Thresholds, non-linearities, and system-system interactions/dependencies are all likely to affect these responses. These things will certainly be studied in crewmembers participating in Lunar missions; however, it would be useful to know ahead of time whether any of the effects could be severe enough to cause functionally significant decrements in crew health, safety, or performance during these missions, so that appropriate countermeasures could be provided from the outset.

Various lunar gravity simulation techniques were developed during the Apollo era (e.g., parabolic flight, mechanical off-loading, vertical counter-weighting, underwater activities); these techniques can be used only for short-term simulations (seconds-to-hours). All are capable of simulating the musculoskeletal loading on the Moon, but only parabolic flight can provide a high-fidelity simulation of the physiological loading for the cardiovascular and sensory-motor systems. The long-term exposures (weeks-to-months) required to simulate lunar outpost missions have been attempted in humans only by using head-up-tilt (HUT) bed rest models. While such models can provide accurate static loading along the long body axis, they cannot eliminate the (nearly) orthogonal components of the gravity vector, nor can they allow for high-fidelity dynamic simulations. Nevertheless, within limits, they might provide insight into the expected adaptive responses of the bone, muscle, and cardiovascular systems to prolonged lunar gravity exposure. The Flight Analogs Project is investigating the HUT model as a potential analog to physiological changes induced by the partial gravity environment of the lunar surface.

1.4.5 ELEMENTS AND PROJECTS RESPONSIBLE FOR THE RESEARCH (WHO)

Each risk is allocated to one of the five research elements within the HRP, and the IRP identifies which Element is responsible for the identified risk. Three of the HRP Elements are single project elements: Behavioral Health and Performance (BHP), Exploration Medical Capability (ExMC) and Space Radiation, and the responsible Element is identified at the risk level, but they are responsible also for all gaps and tasks addressing the risks. Two HRP Elements, Human Health Countermeasures (HHC) and Space Human Factors and Habitability (SHFH) are multi-project Elements. Thus, the Element is identified at the risk level, and the responsible project within the Element is identified at the Gap level. The following HHC abbreviations are used throughout the IRP to designate the responsible project: EPSP (EVA Physiology and Systems Performance), ECP (Exercise Countermeasure Project), NxPCM (Non-Exercise Physiological Countermeasures), and FAP (Flight Analogs Project). The following abbreviations are used to designate the responsible SHFH project: AEH (Advanced Environmental Health), AFT (Advanced Food Technology), and SHFE (Space Human Factors Engineering).

The HRP's intent is that each study is procured through competitive means, i.e., a NASA Research Announcement (NRA), Request for Proposal (RFP), etc. In some cases, due to timeliness of data, or close interconnectedness with operations or other NASA entities, the HRP will direct a specific study be done. Criteria for these decisions are given in the HRP Science Management Plan. The current and planned procurement method for each task in this research plan is identified. Identification of any investigation as a directed study within the IRP does not signify a commitment on the part of the HRP to implement that study as a directed study without further consideration by the Program Scientist as specified in the Science Management Plan.

It is the HRP's policy that all investigations sponsored by the program will undergo independent scientific merit review. This includes proposals submitted in response to NASA Research Announcements, all directed study proposals, and all unsolicited proposals.

Each Element or Project within an HRP will be reviewed by an independent Standing Review Panel. The Panel's primary responsibility is to review the Element Research Plan and provide recommendations on the scientific or technological approach and portfolio content. Those element research plans ultimately serve as the input to the IRP. Modifications to element research plans will result in modifications to the annual update of the IRP.

1.4.6 DELIVERABLES OF THE RESEARCH (DELIVERABLES)

The focus of this document is to identify deliverables necessary to complete the exploration (lunar and Mars) missions. This plan is NOT intended to mitigate risks associated with the ISS. The ISS is used as a platform to conduct research aimed at mitigating risks to the exploration missions. Some of the research may identify countermeasures, engineering, or operational solutions that would enhance the ISS and reduce risk in use (including to users) of that platform. In those cases, the HRP identifies the necessary deliverables and insertion points for the ISS.

Human health and performance risks can best be mitigated through the space system design. The HRP works closely with the Constellation program to communicate the areas of human health and performance risks, and to help inform engineering and development of the Constellation systems. Mitigation of many human health and performance risks can be accomplished through engineering design and operational constraints, and do not need further research. Decision points in the research schedules are placed to evaluate the adequacy of the approach, research results, and deliverables to meet the intended application.

The first and most desirable approach to mitigating a human health and performance risk is to engineer the risk out of the system. HRP research is intended to reduce the uncertainty in the risk and free mission timelines and design from unnecessary conservatism. To facilitate risk avoidance, the HRP identifies requirements for crew selection, vehicle or mission design.

Some human health and performance risks can be mitigated through application of special space medicine operations procedures. The HRP works closely with the Space Medicine Division at JSC to evaluate the relative risks and to determine if the risks can be mitigated through known procedures. This coordination occurs through HRP participation on the HSRB, and interaction at the Human Systems Risk Forum (HSRF). This board and forum have been set up by the Chief Health and Medical Officer with chairmanship delegated to the JSC Chief Medical Officer. Members of this board consider the range of human health and performance risks, and identify those that can be mitigated through operational procedures vs. those that require further research. The risks addressed in this IRP are those identified by the HSRB as requiring research. The "inform medical operations" deliverables are the results of forum discussions, and research results are integrated into medical requirements or flight operations procedures. The HSRB is also used to evaluate the "deliver countermeasure" deliverable to ensure countermeasures can be adequately transitioned to medical practice.

The HSRB/HSRF is also used to evaluate data at various decision points in the research. The deliverables identified in the plan for "HSRB" utilize the board to concur with the next steps in the research plan.

Several other deliverables are identified throughout this IRP. Two designations are used for standards deliverables. The deliverable to "inform standards" represents the HRP's intent to communicate information to the OCHMO and medical operations that may help interpret the existing standard. The "recommend update for standard" deliverable is used when the research results are expected to change the standard.

2.0 ORIENTATION SUMMARY OF THE RESEARCH PLAN

The development of this document has been evolutionary. The HRP recognizes that the format of this document, while comprehensive in its scope requires an additional high level summary to facilitate a quick understanding of the overall research plan. Further, the integration of research across discipline lines has yet to be completed. A future version of this section is intended to provide a high-level summary of the research approach and planning for each risk. It will also describe how the HRP is performing the integration of research activities across risks.

For each risk in this document, a summary paragraph, an outline of the major gaps, and a short description of the research approach to fill the gaps will be given.

Many activities described in this document address multiple gaps. A different and easier way of viewing their applicability will help to understand the integrated nature of the particular research approach. This section will capture the activities that address multiple gaps, describe the general approach, how each of these activities relates temporally to the research planning and how it relates to the relevant risks. Examples of these activities are the post-flight functional task performance test, the 6-degree head-down bedrest testing environment, and the Lunar bedrest environment.

3.0 ELEMENTS INPUT DESCRIPTION

The format for the Elements' inputs includes graphical depiction via Gantt charts and written discourse to clarify the Element approach. Each input follows the same form. The Risk is reported, along with the criticality to the Lunar Outpost mission and the Mars mission; the Operational Relevance is described; the strategy for mitigation is given; the gaps in knowledge are reported with a brief description; and the activity or activities necessary to address the gap are described. For each activity, the resulting product/deliverable, the required delivery milestone for the deliverable, the required platform, and the Project or organization responsible for implementing the activity are all defined.

3.1 RISKS

Each text description has a description of the risk. These descriptions are verbatim from the PRD, and are reprinted in the IRP as a matter of convenience for the reader. With the title of each risk, the criticality is given. Criticality ratings correspond to the criteria given in Section 1.4.1 of this document.

3.2 CONTEXT OF RISK FOR EXPLORATION

After each risk and description, a paragraph occurs entitled "Operational Relevance and Risk Context." In this paragraph, a description of the relevance to the exploration mission is given. This section also provides the context of how the research plan is built for that risk and describes the need for the research at a very high level.

3.3 STRATEGY FOR MITIGATION

The approach strategy for the mitigation of the risk is outlined in this section. For instance, the strategy may be to first determine space normal physiology, then identify specific countermeasures.

3.4 GAPS

Gaps in our knowledge or in the evidence base exist for each risk. These gaps have several different forms. A gap may exist in our evidence base, which leaves greater uncertainty regarding the likelihood of the risk. A gap may exist in the identification of the appropriate countermeasure. For others, the gap may be in the flight validation of the appropriate countermeasure. For the purposes of this IRP, the gaps are not delineated by type; rather they are simply identified as a gap that must be filled before the risk is mitigated. In some cases, the gap may not require research to close it; the gap can be avoided altogether through specific Constellation design selection.

3.5 TASKS

For each gap, the task (s) required to fill that gap are listed. The task is named and a short description is given. In some cases, a task can address multiple gaps across multiple risks. To

limit the size of this document, a task that addresses more than one gap is named and described once and the description is referred to in the other gaps that it is intended to fill. In addition, the project responsible for implementation of the task is listed, along with the anticipated procurement method. In some cases, the project is not within the Element responsible for the risk. The responsible Element will coordinate with the appropriate project in those cases.

3.6 DELIVERABLES

Each task is designed to culminate in a deliverable. These deliverables are structured to feed into the Constellation Program, the Office of the Chief Health and Medical Officer, or the Mission Operations Directorate. Several different types of deliverables exist. The following are the types of deliverables used:

Information for Standards

An "Information for Standards" deliverable is used for a task that produces part of the information to update a standard. Because this information is incomplete, the program would not be in a position to recommend a standard update, but it would represent a significant step toward such a recommendation. These tasks can feed into other tasks that also have information for standards, or they can be combined with other "Information for Standards" deliverables to result in a recommended standard update (next deliverable)

Recommended Standard Update

A "Recommended Standard Update" deliverable is mandated when the program is ready to provide the OCHMO with a recommended update to health or performance standards. This is usually done using the results of several tasks and then integrated into one recommendation for update. A key test of when to use this as a deliverable is that the program should be ready to actually write the text for the recommended standard update. Since the standards are applied in a broad spectrum for design and operations, these deliverables can be linked to any of the system design or mission operations milestones shown in the blue section at the top of the chart. They should be applied as early in the design phase or mission operations development phase as is possible, so, most often, they are necessary prior to Systems Requirements Review.

Informing Mission Operations

This form of deliverable is needed when the information is directly useful to affect mission planning. Examples include when a deliverable may impose mission operations timelining constraints, such as a new flight rule for sleep schedules or exercise timelines. As the name implies, these deliverables will most often affect the Mission Operations line shown in the blue section of the top of the Gantt charts.

Countermeasure

When a specific protocol is developed and validated to prevent or reduce the severity of a negative outcome identified in one of the risks, this is the form of deliverable. A countermeasure may be medical, physical, or operational entities, such as pharmaceuticals, a device, or a specific exercise routine, respectively. Note that in some cases the countermeasure will also affect

mission operations (in areas like timelines). Though there is no fixed rule on this crossover, the demarcation used for the countermeasure deliverable is that the protocol is specific and extensive enough to require validation in spaceflight. For instance, if a ground task results in a spaceflight task that is called "flight validation studies," it likely is a countermeasure. Similarly, there is no set rule for determining to which Constellation milestone a countermeasure would apply. Some general direction on this, however, is that the countermeasure usually does not affect the design of the spacecraft, and is applied in the mission operations phase as a solution to a problem; thus, the countermeasure deliverables generally affect the mission operations PDR or CDR phases.

Information to Other Elements

This deliverable is used when the task result feeds a gap in some other HRP element. As the IRP matures, we will identify critical dependencies for each gap. These critical dependencies will include, in some cases, information developed under another gap. The need dates for these deliverables are determined by when the other element needs the information, not by Constellation milestones.

Requirements to Other Programs or Elements

The "Requirements to Other Programs or Elements" deliverable is chosen when a task will result in a requirement (or requirements set) given to another program (usually the Constellation Program) or to another element. The task may end up in the requirements on the lighting spectrum in the vehicle, or a requirement may apply to the radiation shielding design, or requirements may be identified that apply to the food system from nutritional risk work. These deliverables often feed the design of the vehicle and its sub-systems. As requirements, they primarily are applied in the Systems Requirements Review timeframe.

Updates to the Human Systems Risk Forum

When a task results in information that must be considered by the medical operations community and/or OCHMO, this deliverable is used. This deliverable is applicable when the rating of the likelihood or consequences of the RMAT may be affected. It is also applied when the results of the study are anticipated by the space medical operations community. As such, the deliverable often is applied in conjunction with the "Informing Mission Operations" deliverable.

3.7 REQUIRED DELIVERY MILESTONE

Key milestones within the Constellation Program development drive the required date for the HRP deliverables. For instance, design requirements typically must be defined by the appropriate System Requirements Review. Design solutions and technology typically must be defined to a TRL6 level by the Preliminary Design Review. This section documents the schedule drivers for the delivery milestones.

3.8 REQUIRED PLATFORMS

This section defines the platform required to perform the research. Platforms can be designated as ground analog environments, such as NEEMO, Antarctica, etc., or the platform may be a space-based one, such as the Shuttle or the ISS. Also, the lunar surface is a platform that is

anticipated in some research efforts. If the ISS is required, a summary of the following resource requirements is given: Number of subjects, Initial Upmass, Upmass/Subject, Downmass, Crew Time/Subject, and Post-Flight Baseline Data Collection Time.

3.9 PROJECT OR ORGANIZATION RESPONSIBLE FOR THE IMPLEMENTATION OF ACTIVITY

Within the HRP elements, there are one or many projects chosen to implement the element research plan. The project is identified in this section. In some cases, organizations outside the element are responsible for implementation of the research, such as the NSBRI or even an international partner. These organizations are identified within this section.

This section indicates the project with primary responsibility for implementing the activity. In some cases, the project is not within the element responsible for the risk. The element responsible will coordinate with the appropriate project in those cases.

Discipline teams include the participation of operations personnel, the NASA research discipline experts, and the NSBRI. In several cases, the primary responsibility is shown as that of NASA; however, that does not mean that the NSBRI is not participating at all. The NSBRI participates through the discipline teams, as well as through future solicitations.

3.10 GRAPHIC INPUT

Each graphic is supported with text that provides a more thorough level of detail. Figure 2 shows an example of a Gantt chart, labeling each section of the chart. Each Gantt chart is associated with one of the 27 PRD Risks. The element to which the risk is allocated is identified in the upper left corner. The research gaps are identified by name and number along the left side for each risk. Under each gap are the identified activities required to fill the gap. Each activity is identified by name and the acronym of the project or organization responsible for implementing the activity. In some cases, the organization responsible for implementing the activity may not be directly controlled by the element responsible for the risk. The schedule of each activity is shown on the graphic and an arrow shows deliverables resulting from the activity. The activities are color-coded per the legend given. A number on each text deliverable description relates the deliverable to the need date, shown by the gray numbered arrows at the top of the chart.

3.11 DECISION POINTS

Several key decision points have been placed in the plan. At these key decision points, the appropriate forward path for the research will be reevaluated. The decision points are cast in a "Yes/No" form, and it is anticipated that at these points, the responsible element will review the overall, current state of the evidence, and review the appropriate approach to the forward plan. Where applicable, the Science Management Office will concur and, if necessary, the appropriate Project Standing Review Panel may be convened to deliberate and make recommendations. Criteria for making the decision will be determined on a case-by-case basis and will be consistent with the overall management structure documented in the Science Management Plan. In many cases, a task addresses more than one risk.

RISK OF IMPAIRED ABILITY TO MAINTAIN CONTROL OF VEHICLES AND OTHER COMPLEX SYSTEMS –
criticality: lunar outpost – D, mars – I

It has been shown that long duration Spaceflight alters sensorimotor function which manifests as changes in locomotion, gaze control, dynamic visual acuity, and perception. These changes have not specifically been correlated with real time performance decrements. The possible alterations in sensorimotor performance are of interest for Mars missions due to the prolonged microgravity exposure during transit followed by landing tasks. This risk must be better documented and NS changes must be better correlated with performance issues.

Context of Risk for Exploration

New evidence regarding landing performance indicates that research into these types of issues is not a high priority for Shuttle or ISS. However, since Mars operational scenarios are still TBD, it is agreed that the ISS should be utilized to gather the data required to define the research that might be needed to enable future Mars mission operations. Therefore, this risk is considered to have a higher priority than the others within the sensorimotor discipline do. Spaceflight data should be collected (RMS, SSRMS, docking, glove box ops, Soyuz landings, etc.). In addition, performance related to neurosensory dysfunction should be used to determine the need for further research and countermeasure development.

Strategy for Mitigation

Space normal must first be defined for this risk; hence, data mining tasks are ongoing. Once space normal is defined, the data will be presented to the Human System Risk Forum and it will be decided if countermeasures need to be developed. In addition, the NRA solicitation process was utilized to obtain proposals to determine any manual and visual control deficits.

Gaps

SM1: What is the relationship between the mode of in-flight exercise and post-flight sensorimotor performance? The sensorimotor team should data mine to determine if data exist for this gap.

Task: (NxPCM – via directed study) Sensorimotor Performance Data Mining It is proposed that the type and amount of in-flight exercise performed by crewmembers may influence post-flight disturbance in balance and locomotion. Exercise logs for both US and Russian crewmembers will be evaluated to determine the relationship between the types of in-flight exercise performed and post-flight sensorimotor performance.
Deliverables: Data will be collected and passed to HSRF. It will also be used to inform ECP of any exercise and sensorimotor issues and used to provide any updates to the sensorimotor standard.
Required Delivery Milestone: There is no required delivery milestone for this task.
Required Platforms: Access to Flight Medicine, JSC Biomedical Research Laboratory data, and LSDA databases is necessary for the data mining study.

SM2: What is the time course of recovery of sensorimotor function after long duration space flight? This data can be used to make scheduling recommendations for planetary post-landing operations.

Task: (NxPCM – via directed study) Sensorimotor Performance Recovery Data Mining After long duration space flights, astronauts require time to return to pre-flight sensorimotor performance. This study will compile the recovery data from previous long duration astronauts to determine the average amount of time that is required for sensorimotor function recovery.
Deliverables: Data will be collected and passed to HSRF. It will also be used to inform Flight Medicine of any recommended recovery protocols and used to provide any updates to the sensorimotor standard.
Required Delivery Milestone: There is no required delivery milestone for this task.
Required Platforms: Access to Flight Medicine, JSC Biomedical Research Laboratory data, and LSDA databases is necessary for the data mining study.

Task: TBD Study (NRA) Sensorimotor Performance Recovery and Rehabilitation Proposals are being solicited in the 2009 NRA to answer the following goals: 1) to assess sensorimotor function; 2) to prescribe and implement a set of rehabilitation exercises that aid in quick adaptation to the new gravitational environment; and 3) to evaluate crewmember abilities to safely perform mission operations.
Deliverables: The deliverable should be a new, innovative, hand-held smart-device requiring minimal power and mass for assessment and rehabilitation of crewmembers on lunar and Mars surfaces.
Required Delivery Milestone: TBD
Required Platforms: TBD

SM3: What is the appropriate rehabilitation protocol for sensorimotor function? It is unknown if recovery/rehabilitation exercises can facilitate quick adaptation to the fractional gravity environment of the Moon and Mars.

Task: TBD Study (NRA) Sensorimotor Performance Recovery and Rehabilitation Proposals are being solicited in the 2009 NRA to answer the following goals: 1) to assess sensorimotor function; 2) to prescribe and implement a set of rehabilitation exercises that aid in quick adaptation to the new gravitational environment; and 3) to evaluate crewmember abilities to safely perform mission operations.
Deliverables: The deliverable should be a new, innovative, hand-held smart-device requiring minimal power and mass for assessment and rehabilitation of crewmembers on lunar and Mars surfaces.
Required Delivery Milestone: TBD
Required Platforms: TBD

SM4: Can previous performance data be correlated with clinical observations? Attempts should be made to obtain ISS EVA performance data from previous missions. If that is not feasible, a strategy should be developed to gather forward data. No research should be undertaken until this evidence is obtained.

Task: (NxPCM – via directed study) Performance Data Mining This study will compile data recorded from previous missions regarding ISS EVAs. The purpose of this data-mining task is to gain additional operational data. Lessons learned from this analysis can be applied to the Constellation Program to ensure that the evidence for sensorimotor changes in crew performance as a result of space flight is thoroughly assessed.
Deliverables: Initial product is space normal data from a data-mining task. If results indicate that no data exist, then data should be obtained using ISS flight studies.
Required Delivery Milestone: There is no required delivery milestone for this task.
Required Platforms: Access to Flight Medicine, JSC Biomedical Research Laboratory data, and LSDA databases is necessary for the data mining study. ISS may be required to obtain space normal data.

SM5: What are the effects of disorientation and inter-individual differences on supervisory control, docking, RMS etc? Evidence must be gathered to support this gap. No research should be undertaken until this evidence is obtained.

Task: (NxPCM – via directed study) Performance Data Mining This study will compile data recorded from previous missions regarding manual control and landing. The purpose of this data-mining task is to gain additional operational data and insight regarding Shuttle landings that occurred outside the operational limits to determine the multi-factorial causes that led to the landing outcomes. Lessons learned from this analysis can be applied to the Constellation Program to ensure that the evidence for sensorimotor changes in crew performance as a result of space flight is thoroughly assessed. Data will also be gathered from available data from RMS operations, EVAs, and Shuttle/Soyuz docking operations relevant to manual control.
Deliverables: Initial product is space normal data from a data-mining task. If results indicate that no data exist, then data should be obtained using ISS flight studies.
Required Delivery Milestone: There is no required delivery milestone for this task.
Required Platforms: Access to Flight Medicine, JSC Biomedical Research Laboratory data, and LSDA databases is necessary for the data mining study. If data do not exist, the ISS is required.

SM6: Can a seated manual/visual performance assessment after long-duration spaceflight be completed? It is necessary to determine if a crewmember can land a vehicle after six months in microgravity. This gap needs to be placed in the context of the expected operating environment of future vehicles. Design of future vehicles should account for human factors in the cockpit and task design to avoid provocative movements or physically difficult tasks.

Task: (NxPCM – via NRA)

Manual/Visual Control Study – TBD

Proposals were solicited in the 2008 NRA to answer the following questions. What is the decrement in manual/visual performance following long-duration spaceflight? What are the mechanisms of the decrement? What countermeasures are needed?

Deliverables: Initial product will be completion of an ISS pre- and post-flight study to determine seated manual/visual control performance (i.e., landing a spacecraft).

Required Delivery Milestone: FY2023 – countermeasure required for exploration missions

Required Platforms: ISS is required for this study; long-duration crews are needed.

# of Subjects	Initial Upmass (kg)	Upmass (kg/subject)	Downmass (kg/subject)	Crew Time/Subject	Post-Flight BDC Time (hrs)
12	None	None	None	None	2.5

Task: (NxPCM – with ESA)

Ambiguous Tilt and Translation Motion Cues After Space Flight/Otolith Assessment during Post-Flight Re-Adaptation

This experiment is designed to explore the physiological basis for disorientation and tilt-translation disturbances reported by crewmembers when making head movements following re-entry, and to evaluate adverse operational implications of these disturbances. In addition, it is intended to examine assess human otolith function by measuring: unilateral otolith-ocular responses (OOR); an estimation of subjective visual vertical (SVV) during unilateral otolith stimulation; and unilateral vestibular evoked myogenic potentials (VEMP) during post-flight re-adaptation. This is a joint HRP/ESA investigation.

Deliverables: The product will be further information regarding sensorimotor adaptations to spaceflight.

Required Delivery Milestone: There is no required delivery milestone for this task.

Required Platforms: ISS is required for this study; long-duration crews are needed.

Task: (NSBRI)

Development of Countermeasures to Enhance Sensorimotor Adaptation

This study is developing a comprehensive training program that will enhance astronauts' ability to "learn how to learn," leading to rapid adaptation to a new gravity environment. The training program involves exposure to modified visual flow along with alterations in the support surface designed to enhance subject adaptability. The researchers will also determine the short- and long-term (10 days to 6 months) retention rates after the training program.

Deliverables: Initial product will be a ground-based evaluation of a potential countermeasure.

Required Delivery Milestone: FY2023 – countermeasure required for exploration missions

Required Platforms: This is a ground-based investigation.

SM10: There are no stated acceptable ranges of cognitive and psychomotor performance. HHC has closed this gap; it has been incorporated into BHP. Refer to The Risk of Performance Errors Due to Sleep Loss, Fatigue, Circadian Desynchronization and Work Overload, Gap Sleep2 for details

SM13: Incorporate vestibular assessments within the in-flight periodic exams.

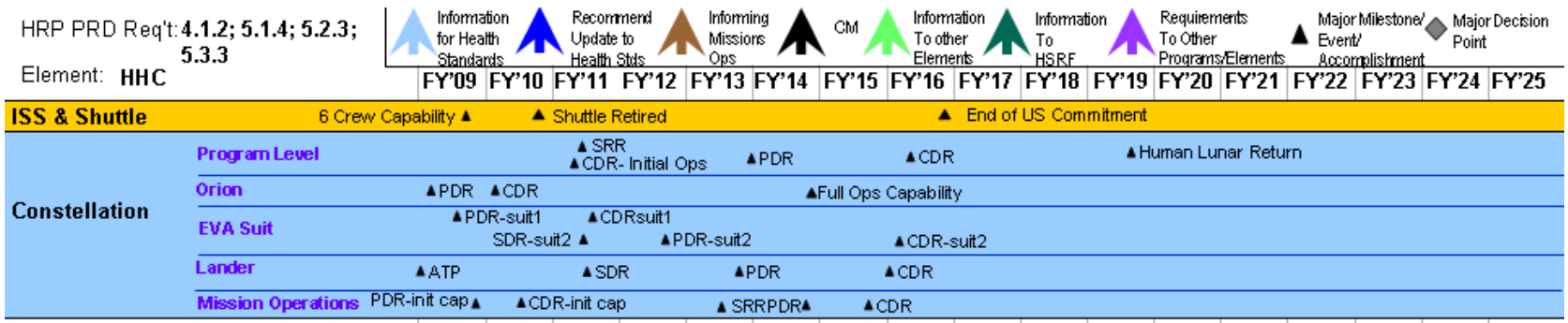
SM15: Need to adopt a multi-disciplinary approach to identify crewmembers at greatest risk of falls; also need to implement and track directed rehabilitation

SM16: Need to insure that astronauts at risk of falls are accompanied until the risk diminishes to acceptable levels.

SM17: Require an astronaut post-flight fall risk assessment that should be a coordinated effort between crew surgeons, ASCRs, and discipline researchers. There is no research required for these gaps; they will be taken to HSRF to determine any closeout actions.

SM11: Need to provide alternate sources for spatial orientation.

SM12: Need to develop standards for spaceflight cockpit control displays and inputs. HHC has closed these two gaps; they have been incorporated into SHFH. Refer to the Risk of Error due to Inadequate Information gaps SHFE3.1.2.2.2.1 and SHFE3.1.2.2a for details.

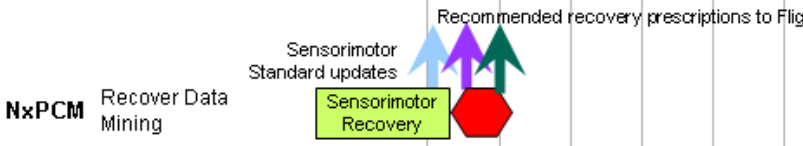


Note: These activities mitigate a risk to a long-duration Lunar and Mars missions. The activities are conducted in the 2008-2020 timeframe because of the availability of ISS as a Mars transit analog.

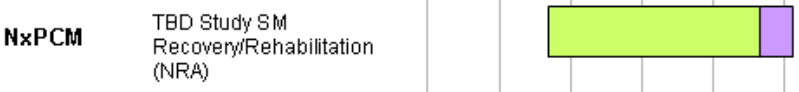
Risk of Impaired Ability to Maintain Control of Vehicles and Other Complex Systems

Gap: (SM1) Relationship between in-flight exercise and post-flight sensorimotor performance.

Gap: (SM2) What is time course of recovery of sensorimotor function after long duration space flight?



Gaps: (SM2) What is time course of recovery of sensorimotor function after long duration space flight?
(SM3) What is the appropriate rehabilitation protocol for sensorimotor function?



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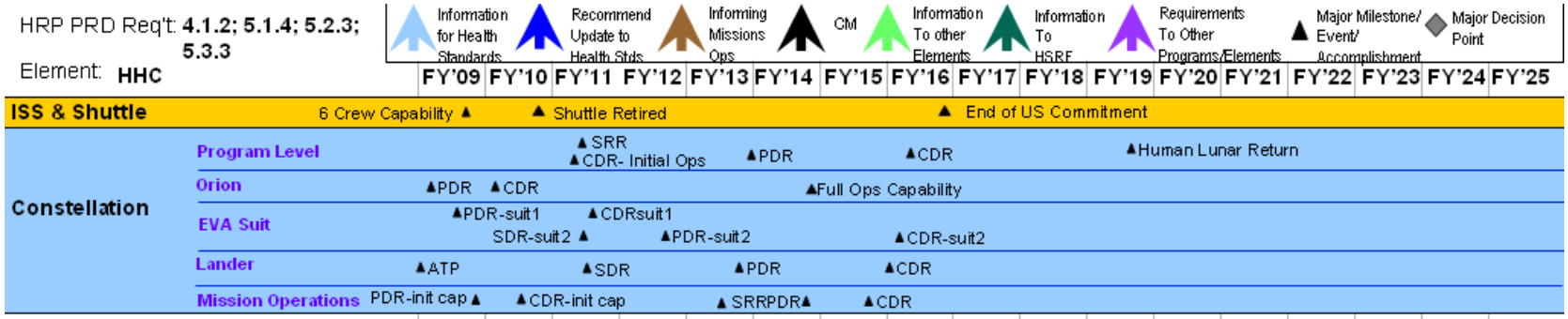
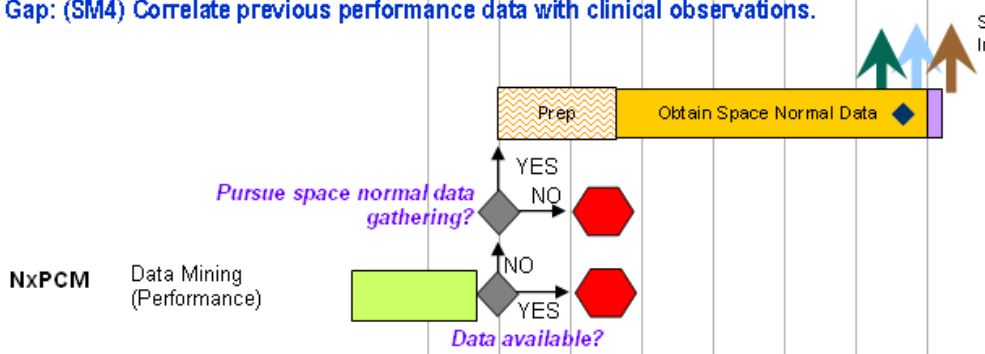


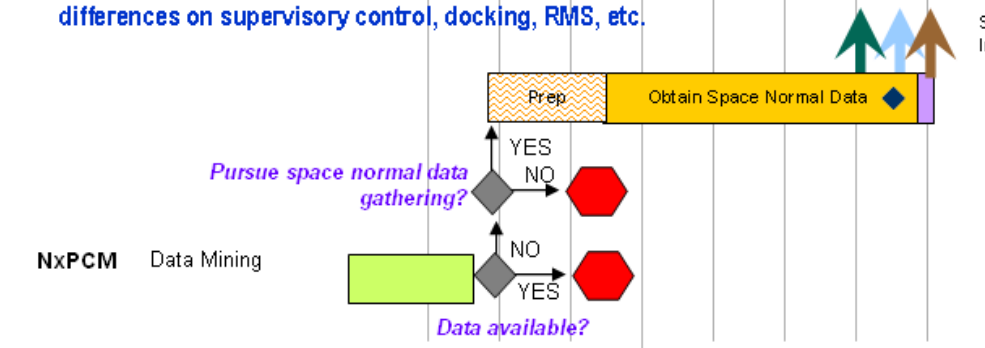
Note: These activities mitigate a risk to a long-duration Lunar and Mars missions. The activities are conducted in the 2008-2020 timeframe because of the availability of ISS as a Mars transit analog.

Risk of Impaired Ability to Maintain Control of Vehicles and Other Complex Systems

Gap: (SM4) Correlate previous performance data with clinical observations.



Gap: (SM5) Effects of disorientation and inter-individual differences on supervisory control, docking, RMS, etc.



◆ *These studies can utilize the same crew members, thus reducing the total subjects required as shown by the graphic.*

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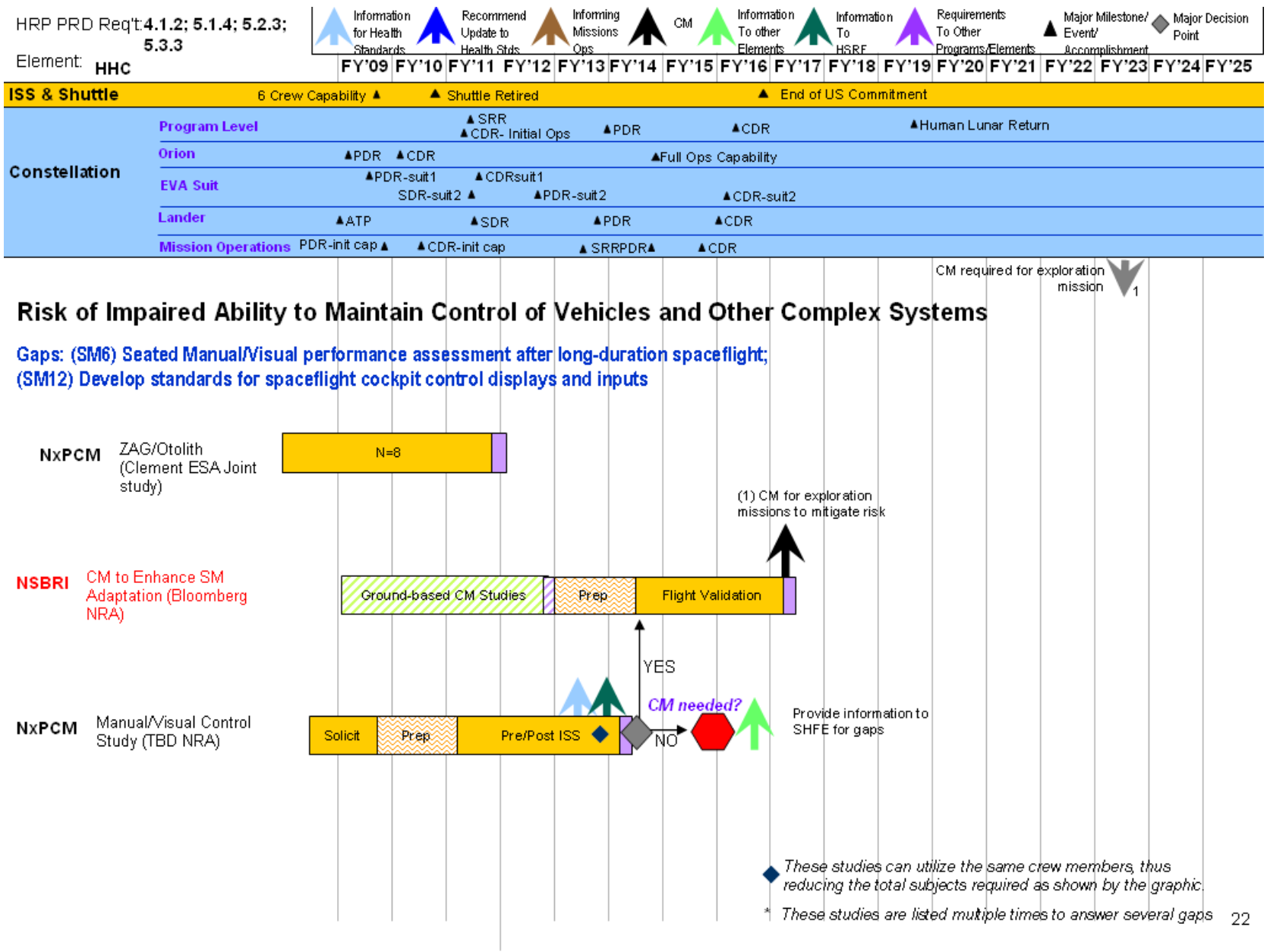
HRP PRD Req't: 4.1.2; 5.1.4; 5.2.3; 5.3.3
Element: HHC
Information for Health Standards
Recommend Update to Health Stds
Informing Missions Ops
CM
Information To other Elements
Information To HSRF
Requirements To Other Programs/Elements
Major Milestone/ Event/ Accomplishment
Major Decision Point
FY'09 FY'10 FY'11 FY'12 FY'13 FY'14 FY'15 FY'16 FY'17 FY'18 FY'19 FY'20 FY'21 FY'22 FY'23 FY'24 FY'25
ISS & Shuttle
6 Crew Capability
Shuttle Retired
End of US Commitment
Constellation
Program Level
SRR
CDR- Initial Ops
PDR
CDR
Human Lunar Return
Orion
PDR
CDR
Full Ops Capability
EVA Suit
PDR-suit1
CDRsuit1
SDR-suit2
PDR-suit2
CDR-suit2
Lander
ATP
SDR
PDR
CDR
Mission Operations
PDR-init cap
CDR-init cap
SRRPDR
CDR
CM required for exploration mission
1
Risk of Impaired Ability to Maintain Control of Vehicles and Other Complex Systems
Gaps: (SM6) Seated Manual/Visual performance assessment after long-duration spaceflight;
(SM12) Develop standards for spaceflight cockpit control displays and inputs
NxPCM
ZAG/Otolith (Clement ESA Joint study)
N=8
(1) CM for exploration missions to mitigate risk
NSBRI
CM to Enhance SM Adaptation (Bloomberg NRA)
Ground-based CM Studies
Prep
Flight Validation
YES
CM needed?
NO
NxPCM
Manual/Visual Control Study (TBD NRA)
Solicit
Prep
Pre/Post ISS
Provide information to SHFE for gaps
These studies can utilize the same crew members, thus reducing the total subjects required as shown by the graphic.
* These studies are listed multiple times to answer several gaps
22